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UCRL-ID-145389

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December 16, 2002

This work was performed under the auspices of the U.S. Department of Energy by University of California, Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

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01-ERD-026

Metals are used in structural engineering applications because they can yield and deform before they break. However, under certain conditions of dynamic loading, metals can fail prematurely. This behavior is often associated with shear localization phenomena, with a shear band acting as a precursor to crack formation. These phenomena have been observed in metals for some time, however modeling this behavior in a continuum simulation code has met with very limited success. We are pursuing a series of model experiments closely linked to new model development in order to gain a fundamental understanding of shear localization and fracture.

Many NNSA and DoD related missions require modeling and simulation of the response of metals to high explosive (HE) loading and whether those metals fail or fracture. HE loading differs from the loading experienced by a specimen in a traditional engineering application. In HE loading, the first process to occur is the passage of a strong shock through the metal due to detonation. This shock completely changes the microstructure of the metal by inducing intense dislocation multiplication, sometimes accompanied by the formation of deformation twins. This change in microstructure strongly modifies the mechanical response of the metal, changing its yield strength, work hardening rate, and strain to failure. Only after this complete change of microstructure does the metal start to deform due to the velocity imparted by the shock and the further acceleration from the high pressure HE detonation gasses.

Our multi-disciplinary approach couples experiments with the development of a new simulation capability aimed at capturing the important physics involved with failure and fracture. The experimental approach is to break down the process into two steps, first by creating microstructures in our test specimens that are representative of the shocked state and then performing the mechanical and fracture tests.

The pre-shocked microstructure is induced by laser shock processing (LSP). This method is considerably easier and less expensive than recovering material from HE driven experiments. The first year of the experimental effort was spent in determining the appropriate LSP conditions for the materials of interest. The mechanical properties were measured by tensile tests at differing strain rates. The microstructures were characterized before and after deformation and the differing mechanical response could be explained based on the differing microstructural evolutions observed. The second year was spent developing the fracture toughness testing methodology. We have chosen an elasto-plastic analysis of the critical strain energy release rate to characterize the fracture toughness. It is appropriate for the 1mm thick specimens made necessary by the LSP.

The modeling and simulation effort has been centered on building a simulation capability suited to the unique challenges posed by fracture and failure. The large strains associated with ductile failure dictates the use of an Eulerian code. The approach incorporates explicitly conservative schemes in the quantities of energy, density, and momentum and so should predict wave structures accurately. The code will be inherently three dimensional, parallel in implementation, and incorporate adaptive mesh refinement. These capabilities are enabled by building the code with the SAMRAI toolbox developed in CASC. A working version of the code now exists and the simulation shown in Figure 1 is an example.

In FY03 the project will concentrate on characterizing the process zone surrounding the tip of a propagating crack.

Figure caption: Simulation of a shock interacting with a soft inclusion in Cu. The shock has passed through the inclusion and colors indicate levels of plastic strain.